Numerical sensitivity analysis of contact forces in several TKAs during squatting

+[1]Innocenti, B; [2]Pianigiani, S; [1]Labey, L; [2]Corvi, A; [3]Victor, J; [4]Bellemans J
+[1]European Centre for Knee Research, Smith&Nephew, Leuven, Belgium, [2]Department of Mechanics and Industrial Technology, University of Florence, Florence, Italy, [3]Department of Orthopaedics , AZ St-Lucas, Brugge, Belgium , [4]Department of Orthopaedic Surgery, U.Z. Pellenberg, K.U. Leuven
bernardo.innocenti@smith-nephew.com

INTRODUCTION:

Total Knee Arthroplasty (TKA) is a very successful surgical procedure, but patients with difficulties or pain during motion still persist. Patient outcomes in TKA surgery can be affected by implant design, alignment or patient-related anatomical factors. To evaluate the influence of some of these factors on contact forces, a numerical sensitivity analysis was performed on several TKAs during squatting.

METHODS:

A physiological leg model was obtained from a CT of a cadaver leg and the physiological soft tissue insertion points were taken from literature [1]. Four different TKA prostheses were implanted according to surgical guidelines:

1. A conventional fixed bearing, posterior stabilized (PS) designs: Genesis II PS (Smith&Nephew, Inc.);
2. A fixed bearing, high flex design: Journey BCS (Smith&Nephew, Inc.);
3. A mobile bearing design: EPP (Smith&Nephew, Inc.);
4. A hinge prosthesis design: RT-PLUS (Smith&Nephew, Inc.).

According to previous experiments [2], for each prosthesis a deep squat of 120° with a physiologic 45 pounds (~200N) constant hip load was simulated using LifeMOD/KneeSIM 2007.0.5 (LifeModeler, Inc., San Clemente, California), a validated, dynamic, musculoskeletal modeling system (fig. 1-2).

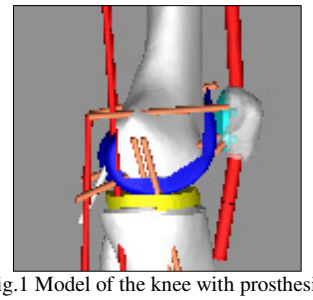

Fig.1 Model of the knee with prosthesis, muscles and soft tissues

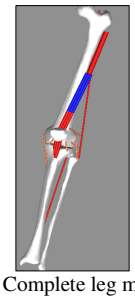

Fig. 2 Complete leg model

For each TKA, the sensitivity of the contact forces to surgical alignment and to patient related anatomical factors was evaluated. The following configurations were analyzed:

1. the theoretical configuration corresponding to optimal surgical technique and physiological anatomy;
2. the change in location over ± 5mm of both proximal and distal insertion points of MCL, LCL and patellar tendon in medio-lateral (ML), antero-posterior (AP) and proximo-distal (PD) directions to simulate the effect of abnormal anatomy or ligament release;
3. the change in position of the tibial component in ML and AP direction over ± 3mm;
4. the change in orientation of the tibial component in flexion-extension (FE) and abduction-adduction (AA) over ± 3° and in internal-external (IE) orientation over ± 5°;
5. the change in position of the patella in height, simulating patella alta (BP index of 1.29) and patella baha (BP index of 0.59) [3-4];
6. the change in orientation of the patellar component in IE orientation over ± 10°.

For each configuration, the tibiofemoral (TF), the patellofemoral (PF) and, for the two PS design, the post-cam forces were extracted.

RESULTS:

For all models, the maximum contact forces during descent and ascent were obtained. Contact forces were expressed in terms of a body weight of 160 pounds (~ 712 N).

Figure 3 and 4 show the extracted PF and TF maximal contact forces, respectively, for all prostheses in the theoretical configuration and after a patellar component internal and external rotation.

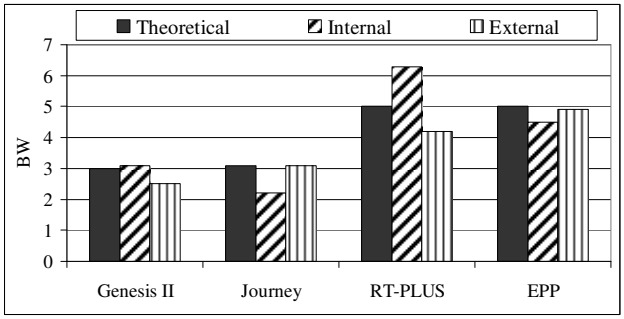

Fig. 3 Patellofemoral maximal contact force in several prostheses during squatting

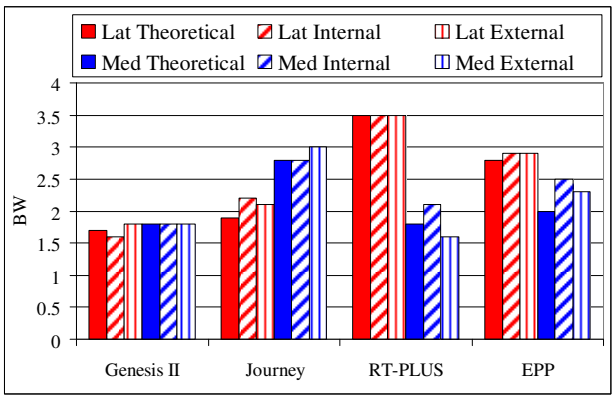

Fig. 4 Lateral and medial maximal tibiofemoral contact forces in several prostheses during squatting

The sensitivity analysis showed that PF contact forces are mostly affected by tibial component AP position, by patella position (alta-baha) and by patellar component IE orientation. The maximum total PF contact forces changed between -55% and +67% during patellar translation from baha to alta respectively. Positions of ligament insertion points did not influence the forces appreciably and changes are always less than 10%. TF contact forces are mostly affected by translation of the MCL insertion locations, up to 49% per 5mm of anterior translation. This force is affected to a lesser extent by patella position and patellar component orientation, up to 25% per 10° patella internal rotation. In the two PS designs, the force on the post is mostly influenced by the MCL insertion points and the patella configurations. The force on the post increased 19% for 3 mm anterior translation of the MCL and the increase was nearly 48% per 10° of patellar component's internal rotation.

DISCUSSION:

Understanding the effect of components positioning on the biomechanical behavior of the knee is fundamental to understanding the implication of malalignment on implant behavior and on TKAs life expectancy. In this project the effects of some factors on contact forces in the knee were analyzed for different prosthesis design. It was shown that, irrespective of implant design, contact forces can change significantly even for small changes in position of components and insertion points.

REFERENCES:

[1] Victor et al., The Knee 2009
[2] Victor et al., AJSM 2009
[3] Luyckx et al., JBJS [B] 2009
[4] Blackburne et al., JBJS [B] 1977